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**Langeslag**

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(54) **DOWNHOLE FLOW CONTROL DEVICE AND METHOD**

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(73) Assignee: **Baker Hughes Incorporated**, Houston, TX (US)

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**E21B 34/06** (2006.01)  
**E21B 43/10** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **E21B 34/06** (2013.01); **E21B 43/10** (2013.01)

(58) **Field of Classification Search**  
CPC ..... E21B 34/06; E21B 43/10  
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See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

266,848 A 10/1882 Lewis  
1,362,552 A 12/1920 Alexander et al.

1,488,753 A 4/1924 Kelly  
1,580,325 A 4/1926 Leroy  
1,649,524 A 11/1927 Hammond  
1,915,867 A 6/1933 Penick  
1,984,741 A 12/1934 Harrington  
2,089,477 A 8/1937 Halbert

(Continued)

**FOREIGN PATENT DOCUMENTS**

CN 1385594 12/2002  
GB 1492345 6/1976

(Continued)

**OTHER PUBLICATIONS**

An Oil Selective Inflow Control System; Rune Freyer, Easy Well Solutions; Morten Fejerskov, Norsk Hydro; Arve Huse, Altinex; European Petroleum Conference, Oct. 29-31, Aberdeen, United Kingdom, Copyright 2002, Society of Petroleum Engineers, Inc.

(Continued)

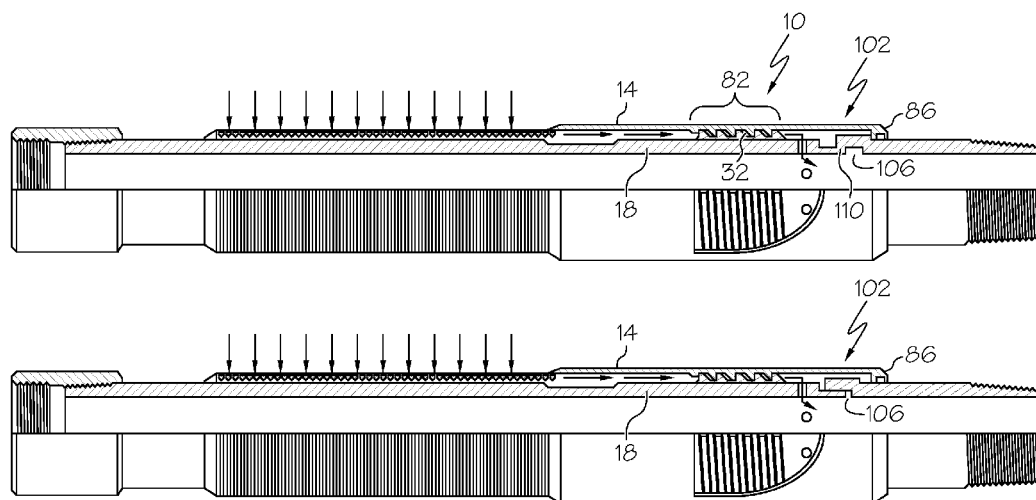
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(57) **ABSTRACT**

A flow control device, including a first member defining a first portion of a flow path and a second member defining a second portion of the flow path. The flow path has a cross sectional flow area defined at least partially by the first member and the second member. A length of the flow path is greater than a largest dimension of the cross sectional flow area, and the cross sectional flow area is adjustable by movement of at least a portion of the first member relative to the second member. A crush zone arranged with at least one of the first member and the second member that can change in length due to loading thereof. A method of adjusting restriction of a flow path is also included.

**16 Claims, 4 Drawing Sheets**



(56)

## References Cited

## U.S. PATENT DOCUMENTS

2,119,563	A	6/1938	Wells	4,944,349	A	7/1990	Von Gonten, Jr.
2,214,064	A	9/1940	Niles	4,974,674	A	12/1990	Wells
2,257,523	A	9/1941	Combs	4,997,037	A	3/1991	Coston
2,391,609	A	12/1945	Wright	4,998,585	A	3/1991	Newcomer et al.
2,412,841	A	12/1946	Spangler	5,004,049	A	4/1991	Arterbury
2,762,437	A	9/1956	Egan et al.	5,016,710	A	5/1991	Renard et al.
2,804,926	A	9/1957	Zublin	5,040,283	A	8/1991	Pelgrom
2,810,352	A	10/1957	Tumlison	5,060,737	A	10/1991	Mohn
2,814,947	A	12/1957	Stegemeier et al.	5,107,927	A	4/1992	Whiteley et al.
2,942,668	A	6/1960	Maly et al.	5,132,903	A	7/1992	Sinclair
2,945,541	A	7/1960	Maly et al.	5,156,811	A	10/1992	White
3,103,789	A	9/1963	McDuff	5,188,191	A	2/1993	Tomek
3,216,503	A	11/1965	Fisher et al.	5,217,076	A	6/1993	Masek
3,240,274	A	3/1966	Solum	5,333,684	A	8/1994	Walter et al.
3,273,641	A	9/1966	Bourne	5,337,821	A	8/1994	Peterson
3,302,408	A	2/1967	Schmid	5,339,895	A	8/1994	Arterbury et al.
3,322,199	A	5/1967	Van Note, Jr.	5,339,897	A	8/1994	Leaute
3,326,291	A	6/1967	Zandmer	5,355,956	A	10/1994	Restarick
3,333,635	A	8/1967	Crawford	5,377,750	A	1/1995	Arterbury et al.
3,385,367	A	5/1968	Kollsman	5,381,864	A	1/1995	Nguyen et al.
3,386,508	A	6/1968	Bielstein et al.	5,384,046	A	1/1995	Lotter et al.
3,399,548	A	9/1968	Burns	5,431,346	A	7/1995	Sinaisky
3,419,089	A	12/1968	Venghiattis	5,435,393	A	7/1995	Brekke et al.
3,446,297	A	5/1969	Elliott et al.	5,435,395	A	7/1995	Connell
3,451,477	A	6/1969	Kelley	5,439,966	A	8/1995	Graham et al.
3,468,375	A	9/1969	States	5,511,616	A	4/1996	Bert
3,612,176	A	10/1971	Bauer et al.	5,551,513	A	9/1996	Surles et al.
RE27,252	E	12/1971	Sklar et al.	5,586,213	A	12/1996	Bridges et al.
3,675,714	A	7/1972	Thompson	5,597,042	A	1/1997	Tubel et al.
3,692,064	A	9/1972	Hohnerlein et al.	5,609,204	A	3/1997	Rebardi et al.
3,739,845	A	6/1973	Berry et al.	5,673,751	A	10/1997	Head et al.
3,791,444	A	2/1974	Hickey	5,803,179	A	9/1998	Echols et al.
3,876,235	A	4/1975	Flint	5,829,520	A	11/1998	Johnson
3,876,471	A	4/1975	Jones	5,831,156	A	11/1998	Mullins
3,918,523	A	11/1975	Stuber	5,839,508	A	11/1998	Tubel et al.
3,951,338	A	4/1976	Genna	5,873,410	A	2/1999	Iato et al.
3,958,649	A	5/1976	Bull et al.	5,881,809	A	3/1999	Gillespie et al.
3,975,651	A	8/1976	Griffiths	5,896,928	A	4/1999	Coon
4,153,757	A	5/1979	Clark, III	5,944,446	A	8/1999	Hocking
4,173,255	A	11/1979	Kramer	5,982,801	A	11/1999	Deak
4,180,132	A	12/1979	Young	6,044,869	A	4/2000	Koob
4,186,100	A	1/1980	Mott	6,068,015	A	5/2000	Pringle
4,187,909	A	2/1980	Erbstoesser	6,098,020	A	8/2000	Den Boer
4,245,701	A	1/1981	Chambers	6,112,815	A	9/2000	Boe et al.
4,248,302	A	2/1981	Churchman	6,112,817	A	9/2000	Voll et al.
4,250,907	A	2/1981	Struckman et al.	6,119,780	A	9/2000	Christmas
4,257,650	A	3/1981	Allen	6,182,755	B1	2/2001	Mansure
4,265,485	A	5/1981	Boxerman et al.	6,228,812	B1	5/2001	Dawson et al.
4,278,277	A	7/1981	Krijgsman	6,253,847	B1	7/2001	Stephenson
4,283,088	A	8/1981	Tabakov et al.	6,253,861	B1	7/2001	Carmichael et al.
4,287,952	A	9/1981	Erbstoesser	6,273,194	B1	8/2001	Hiron et al.
4,332,401	A	6/1982	Stephenson et al.	6,301,959	B1	10/2001	Hrametz et al.
4,390,067	A	6/1983	Willman	6,305,470	B1	10/2001	Woie
4,398,600	A	8/1983	Vazquez	6,325,152	B1	12/2001	Kelley et al.
4,398,898	A	8/1983	Odom	6,338,363	B1	1/2002	Chen et al.
4,410,216	A	10/1983	Allen	6,367,547	B1	4/2002	Towers et al.
4,415,205	A	11/1983	Rehm et al.	6,371,210	B1	4/2002	Bode et al.
4,434,849	A	3/1984	Allen	6,372,678	B1	4/2002	Youngman et al.
4,463,988	A	8/1984	Bouck et al.	6,419,021	B1	7/2002	George et al.
4,484,641	A	11/1984	Dismukes	6,474,413	B1	11/2002	Barbosa et al.
4,491,186	A	1/1985	Alder	6,505,682	B2	1/2003	Brockman
4,497,714	A	2/1985	Harris	6,516,888	B1	2/2003	Gunnarson et al.
4,512,403	A	4/1985	Santangelo et al.	6,530,431	B1	3/2003	Castano-Mears et al.
4,552,218	A	11/1985	Ross et al.	6,561,732	B1	5/2003	Bloomfield et al.
4,552,230	A	11/1985	Anderson et al.	6,581,681	B1	6/2003	Zimmerman et al.
4,572,295	A	2/1986	Walley	6,581,682	B1	6/2003	Parent et al.
4,576,404	A	3/1986	Weber	6,622,794	B2	9/2003	Zisk, Jr.
4,577,691	A	3/1986	Huang et al.	6,632,527	B1	10/2003	McDaniel et al.
4,614,303	A	9/1986	Moseley, Jr. et al.	6,635,732	B2	10/2003	Mentak
4,649,996	A	3/1987	Kojicic et al.	6,667,029	B2	12/2003	Zhong et al.
4,817,710	A	4/1989	Edwards et al.	6,679,324	B2	1/2004	Den Boer et al.
4,821,800	A	4/1989	Scott et al.	6,692,766	B1	2/2004	Rubinstein et al.
4,856,590	A	8/1989	Caillier	6,699,503	B1	3/2004	Sako et al.
4,899,835	A	2/1990	Cherrington	6,699,611	B2	3/2004	Kim et al.
4,917,183	A	4/1990	Gaidry et al.	6,712,154	B2	3/2004	Cook et al.
				6,722,437	B2	4/2004	Vercaemer et al.
				6,786,285	B2	9/2004	Johnson et al.
				6,817,416	B2	11/2004	Wilson et al.
				6,820,690	B2	11/2004	Vercaemer et al.

(56)

**References Cited****U.S. PATENT DOCUMENTS**

6,830,104 B2 12/2004 Nguyen et al.  
 6,831,044 B2 12/2004 Constien  
 6,840,321 B2 1/2005 Restarick et al.  
 6,857,476 B2 2/2005 Richards  
 6,863,126 B2 3/2005 McGlothen et al.  
 6,896,049 B2\* 5/2005 Moyes ..... 166/82.1  
 6,913,079 B2 7/2005 Tubel  
 6,938,698 B2 9/2005 Coronado  
 6,951,252 B2 10/2005 Restarick et al.  
 6,959,764 B2 11/2005 Preston  
 6,976,542 B2 12/2005 Henriksen et al.  
 7,011,076 B1 3/2006 Weldon et al.  
 7,032,675 B2 4/2006 Steele et al.  
 7,059,410 B2 6/2006 Bousche et al.  
 7,084,094 B2 8/2006 Gunn et al.  
 7,159,656 B2 1/2007 Eoff et al.  
 7,185,706 B2 3/2007 Freyer  
 7,207,385 B2 4/2007 Smith et al.  
 7,252,162 B2 8/2007 Akinlade et al.  
 7,258,166 B2 8/2007 Russell  
 7,264,047 B2 9/2007 Brezinski et al.  
 7,290,606 B2 11/2007 Coronado et al.  
 7,290,610 B2 11/2007 Corbette et al.  
 7,318,472 B2 1/2008 Smith  
 7,322,412 B2 1/2008 Badalamenti et al.  
 7,325,616 B2 2/2008 Lopez De Cardenas et al.  
 7,360,593 B2 4/2008 Constien  
 7,367,399 B2 5/2008 Steele et al.  
 7,395,858 B2 7/2008 Barbosa et al.  
 7,398,822 B2 7/2008 Meijer et al.  
 7,409,999 B2 8/2008 Henriksen et al.  
 7,413,022 B2 8/2008 Broome et al.  
 7,451,814 B2 11/2008 Graham et al.  
 7,469,743 B2 12/2008 Richards  
 7,581,593 B2 9/2009 Pankratz et al.  
 7,621,326 B2 11/2009 Crichlow  
 7,644,854 B1 1/2010 Holmes et al.  
 7,647,966 B2 1/2010 Cavender et al.  
 7,673,678 B2 3/2010 MacDougall et al.  
 7,757,757 B1 7/2010 Vroblesky  
 7,931,081 B2 4/2011 Sponchia  
 2002/0020527 A1 2/2002 Kilaas  
 2002/0125009 A1 9/2002 Wetzel et al.  
 2002/0148610 A1 10/2002 Bussear et al.  
 2002/0170717 A1 11/2002 Venning et al.  
 2003/0221834 A1 12/2003 Hess et al.  
 2004/0052689 A1 3/2004 Yao  
 2004/0060705 A1 4/2004 Kelley  
 2004/0094307 A1 5/2004 Daling et al.  
 2004/0144544 A1 7/2004 Freyer  
 2004/0159447 A1 8/2004 Bissonnette et al.  
 2004/0194971 A1 10/2004 Thomson  
 2004/0244988 A1 12/2004 Preston  
 2005/0016732 A1 1/2005 Brannon et al.  
 2005/0086807 A1 4/2005 Richard et al.  
 2005/0126776 A1 6/2005 Russell  
 2005/0178705 A1 8/2005 Broyles et al.  
 2005/0189119 A1 9/2005 Gynz-Rekowski  
 2005/0199298 A1 9/2005 Farrington  
 2005/0207279 A1 9/2005 Chemali et al.  
 2005/0241835 A1 11/2005 Burris et al.  
 2005/0274515 A1 12/2005 Smith et al.  
 2006/0032630 A1 2/2006 Heins  
 2006/0042798 A1 3/2006 Badalamenti et al.  
 2006/0048936 A1 3/2006 Fripp et al.  
 2006/0048942 A1 3/2006 Moen et al.  
 2006/0076150 A1 4/2006 Coronado et al.  
 2006/0086498 A1 4/2006 Wetzel et al.  
 2006/0108114 A1 5/2006 Johnson  
 2006/0118296 A1 6/2006 Dybevik et al.  
 2006/0124360 A1 6/2006 Lee et al.  
 2006/0157242 A1 7/2006 Graham et al.  
 2006/0175065 A1 8/2006 Ross  
 2006/0185849 A1 8/2006 Edwards et al.  
 2006/0250274 A1 11/2006 Mombourquette et al.

2006/0272814 A1 12/2006 Broome et al.  
 2006/0273876 A1 12/2006 Pachla et al.  
 2007/0012444 A1 1/2007 Horgan et al.  
 2007/0039741 A1 2/2007 Hailey, Jr.  
 2007/0044962 A1 3/2007 Tibbles  
 2007/0045266 A1 3/2007 Sandberg et al.  
 2007/0056729 A1 3/2007 Pankratz et al.  
 2007/0131434 A1 6/2007 MacDougall et al.  
 2007/0181299 A1 8/2007 Chung et al.  
 2007/0209799 A1 9/2007 Vinegar et al.  
 2007/0246210 A1 10/2007 Richards  
 2007/0246213 A1 10/2007 Hailey, Jr.  
 2007/0246225 A1 10/2007 Hailey, Jr. et al.  
 2007/0246407 A1 10/2007 Richards et al.  
 2007/0272408 A1\* 11/2007 Zazovsky et al. .... 166/278  
 2007/0289749 A1 12/2007 Wood et al.  
 2008/0035349 A1 2/2008 Richard  
 2008/0035350 A1 2/2008 Henriksen et al.  
 2008/0053662 A1 3/2008 Williamson et al.  
 2008/0135249 A1 6/2008 Fripp et al.  
 2008/0149323 A1 6/2008 O'Malley et al.  
 2008/0149351 A1 6/2008 Marya et al.  
 2008/0169099 A1 7/2008 Pensgaard  
 2008/0236839 A1 10/2008 Oddie  
 2008/0236843 A1 10/2008 Scott et al.  
 2008/0251255 A1 10/2008 Forbes et al.  
 2008/0283238 A1 11/2008 Richards et al.  
 2008/0296023 A1 12/2008 Willauer  
 2008/0314590 A1 12/2008 Patel  
 2009/0056816 A1 3/2009 Arov et al.  
 2009/0057014 A1 3/2009 Richard et al.  
 2009/0071646 A1 3/2009 Pankratz et al.  
 2009/0101330 A1 4/2009 Johnson  
 2009/0101342 A1 4/2009 Gaudette et al.  
 2009/0133869 A1 5/2009 Clem  
 2009/0133874 A1 5/2009 Dale et al.  
 2009/0139717 A1 6/2009 Richard et al.  
 2009/0139727 A1 6/2009 Tanju et al.  
 2009/0194282 A1 8/2009 Beer et al.  
 2009/0205834 A1 8/2009 Garcia et al.  
 2009/0301704 A1 12/2009 Dillett et al.  
 2010/0126720 A1 5/2010 Kaiser et al.  
 2011/0042096 A1 2/2011 Nutley et al.

**FOREIGN PATENT DOCUMENTS**

GB 2341405 3/2000  
 JP 59089383 5/1984  
 SU 1335677 8/1985  
 WO 9403743 2/1994  
 WO 0079097 12/2000  
 WO 0165063 9/2001  
 WO 0177485 10/2001  
 WO WO0192681 A1 12/2001  
 WO 02075110 9/2002  
 WO 2004018833 A1 3/2004  
 WO 2006015277 2/2006  
 WO 2008092241 A1 8/2008

**OTHER PUBLICATIONS**

Baker Hughes, Thru-Tubing Intervention, Z-Seal Technology, Z-Seal Metal-to-Metal Sealing Technology Shifts the Paradigm, [http://www.bakerhughes.com/assets/media/brochures/4d121c2bfa7e1c7c9c00001b/file/30574tttintervention\\_catalog-1110.pdf.pdf&fs=4460520](http://www.bakerhughes.com/assets/media/brochures/4d121c2bfa7e1c7c9c00001b/file/30574tttintervention_catalog-1110.pdf.pdf&fs=4460520), 2010 pp. 79-81.  
 Baker Oil Tools, Product Report, Sand Control Systems: Screens, Equalizer CF Product Family No. H48688. Nov. 2005. 1 page.  
 Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority; PCT Application No. PCT/US2010/034747; Mailed Dec. 13, 2010; Korean Intellectual Property Office.  
 Bercegeay, E. P., et al. "A One-Trip Gravel Packing System," SPE 4771, New Orleans, Louisiana, Feb. 7-8, 1974. 12 pages.  
 Burkill, et al. Selective Steam Injection in Open hole Gravel-packed Liner Completions SPE 5958.

(56)

**References Cited****OTHER PUBLICATIONS**

Concentric Annular Pack Screen (CAPS) Service; Retrieved From Internet on Jun. 18, 2008. <http://www.halliburton.com/ps/Default.aspx?navid=81&pageid=273&prodid=PRN%3a%3aIQSHFJ2QK>. Determination of Perforation Schemes to Control Production and Injection Profiles Along Horizontal; Asheim, Harald, Norwegian Institute of Technology; Oudemans, Pier, Koninklijke/Shell Exploratie en Productie Laboratorium; SPE Drilling and Completion, vol. 12, No. 1, March; pp. 13-18; 1997 Society of Petroleum Engineers.

Dikken, Ben J., SPE, Koninklijke/Shell E&P Laboratorium; "Pressure Drop in Horizontal Wells and Its Effect on Production Performance"; Nov. 1990, JPT; Copyright 1990, Society of Petroleum Engineers; pp. 1426-1433.

Dinarvand, R., D'Emanuele, A (1995) The use of thermoresponsive hydrogels for on-off release of molecules, *J. Control. Rel.* 36 221-227.

E.L. Joly, et al. New Production Logging Technique for Horizontal Wells. SPE 14463 1988.

Hackworth, et al. "Development and First Application of Bistable Expandable Sand Screen," Society of Petroleum Engineers: SPE 84265. Oct. 5-8 2003. 14 pages.

Henry Restarick, "Horizontal Completion Options in Reservoirs with Sand Problems". SPE 29831. Mar. 11-14, 1995. pp. 545-560.

Ishihara, K., Hamada, N., Sato, S., Shinohara, I., (1984) Photoinduced swelling control of amphiphilic azoaromatic polymer membrane. *J. Polym. Sci., Polym. Chem. Ed.* 22: 121-128.

International Search Report and Written Opinion; Date of Mailing Jan. 13, 2011; International Appln No. PCT/US2010/034750; International Search Report 5 Pages; Written Opinion 3 Pages.

International Search Report and Written Opinion; Date of Mailing Jan. 27, 2011; International Appln No. PCT/US2010/034758; International Search Report 10 Pages; Written Opinion 3 Pages.

International Search Report; Date of Mailing Jan. 27, 2011; International Application No. PCT/US2010/034752; 3 Pages.

Mackenzie, Gordon ADN Garfield, Garry, Baker Oil Tools, Wellbore Isolation Intervention Devices Utilizing a Metal-to-Metal Rather Than an Elastomeric Sealing Methodology, SPE 109791, Society of Petroleum Engineers, Presentation at the 2007 SPE Annual Technical Conference and Exhibition held in Anaheim, California, U.S.A., Nov. 11-14, 2007, pp. 1-5.

Mathis, Stephen P. "Sand Management: A Review of Approaches and Concerns," SPE 82240, The Hague, The Netherlands, May 13-14, 2003. 7 pages.

Optimization of Commingled Production Using Infinitely Variable Inflow Control Valves; M.M. J.J. Naus, Delft University of Technology (DUT), Shell International Exploration and production (SIEP); J.D. Jansen, DUT and SIEP; SPE Annual Technical Conference and Exhibition, Sep. 26-29 Houston, Texas, 2004, Society of Petroleum Engineers.

Pardo, et al. "Completion, Techniques Used in Horizontal Wells Drilled in Shallow Gas Sands in the Gulf of Mexico". SPE 24842. Oct. 4-7, 1992.

R. D. Harrison Jr., et al. Case Histories: New Horizontal Completion Designs Facilitate Development and Increase Production Capabilities in Sandstone Reservoirs. SPE 27890. Western Regional Meeting held in Long Beach, CA Mar. 23-25, 1994.

"Rapid Swelling and Deswelling of Thermoreversible Hydrophobically Modified Poly (N-Isopropylacrylamide) Hydrogels Prepared by freezing Polymerisation", Xue, W., Hamley, I.W. and Huglin, M.B., 2002, 43(1) 5181-5186.

International Search Report and Written Opinion, Mailed Feb. 2, 2010, International Appln. No. PCT/US2009/049661, Written Opinion 7 Pages, International Search Report 3 Pages.

Tanaka, T., Nishio, I., Sun, S.T., Ueno-Nishio, S. (1982) Collapse of gels in an electric field, *Science*, 218-467-469.

Tanaka, T., Ricka, J., (1984) Swelling of Ionic gels: Quantitative performance of the Donnan Theory, *Macromolecules*, 17, 2916-2921.

"Thermoreversible Swelling Behavior of Hydrogels Based on N-Isopropylacrylamide with a Zwitterionic Comonomer". Xue, W., Champ, S. and Huglin, M.B. 2001, *European Polymer Journal*, 37(5) 869-875.

\* cited by examiner

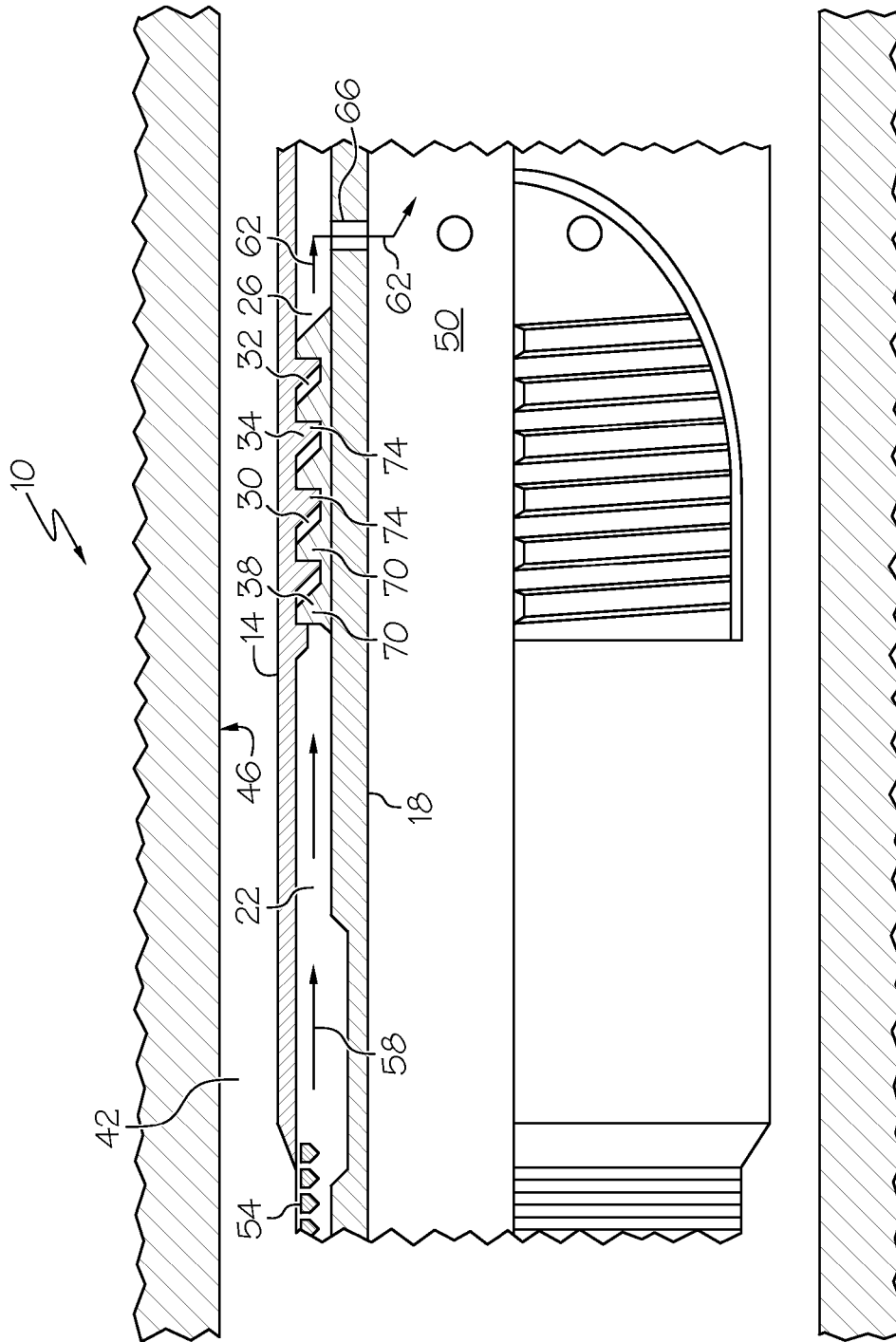


FIG. 1

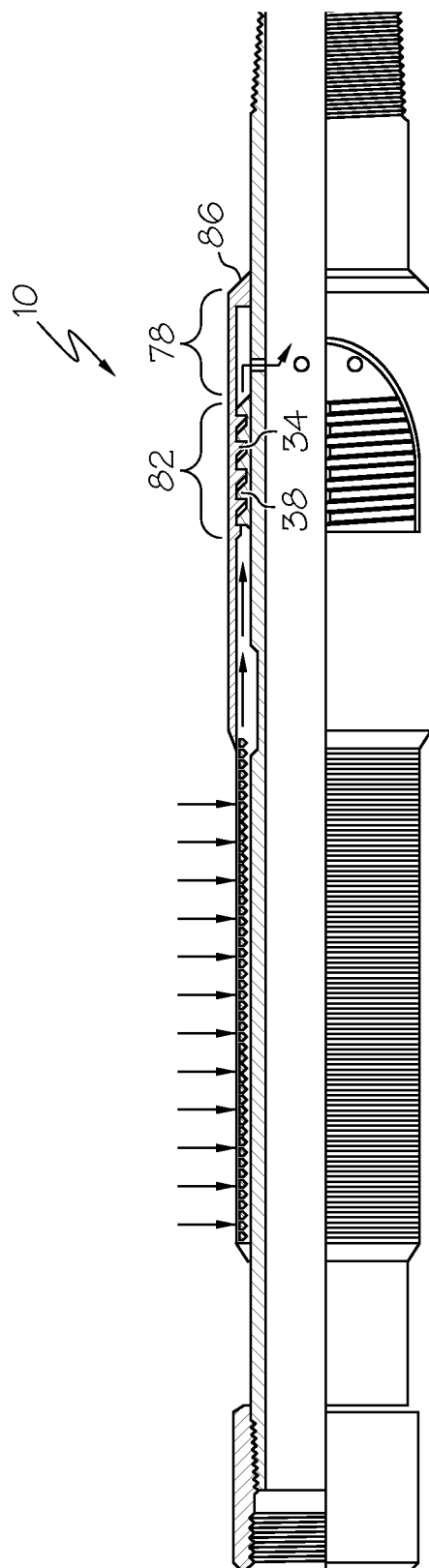


FIG. 2

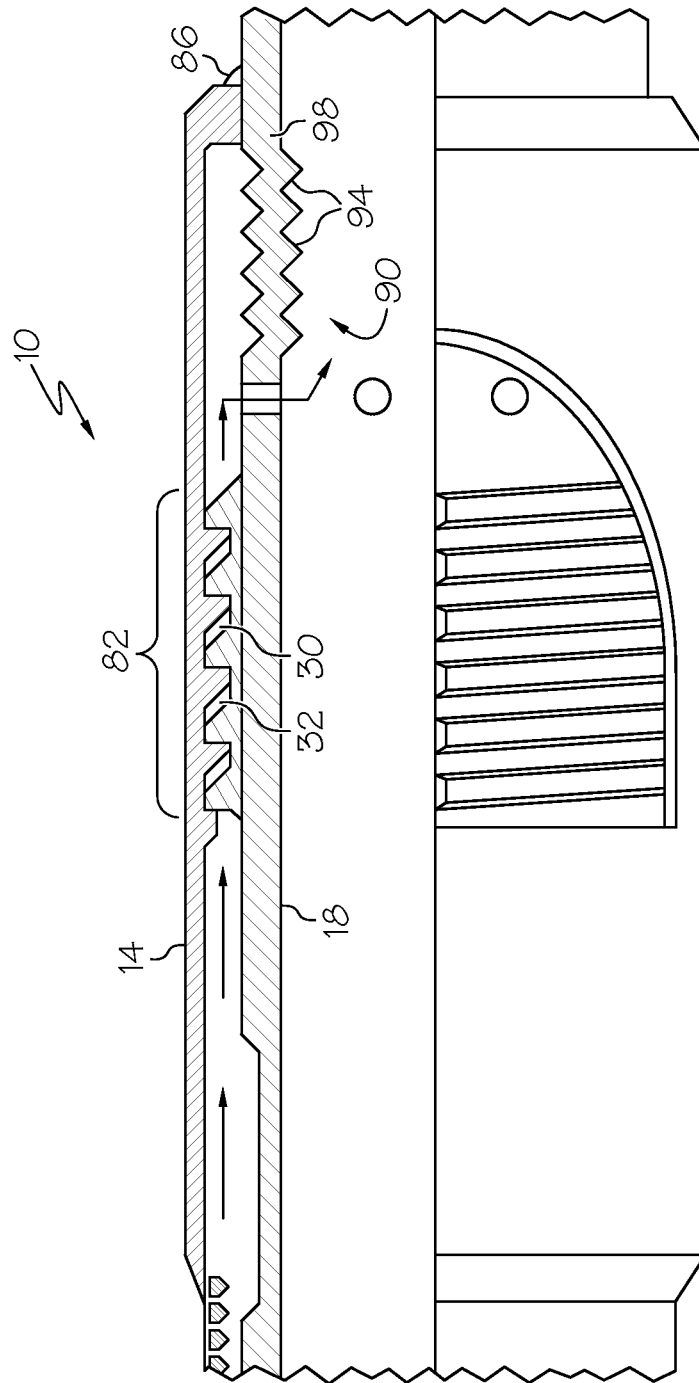


FIG. 3

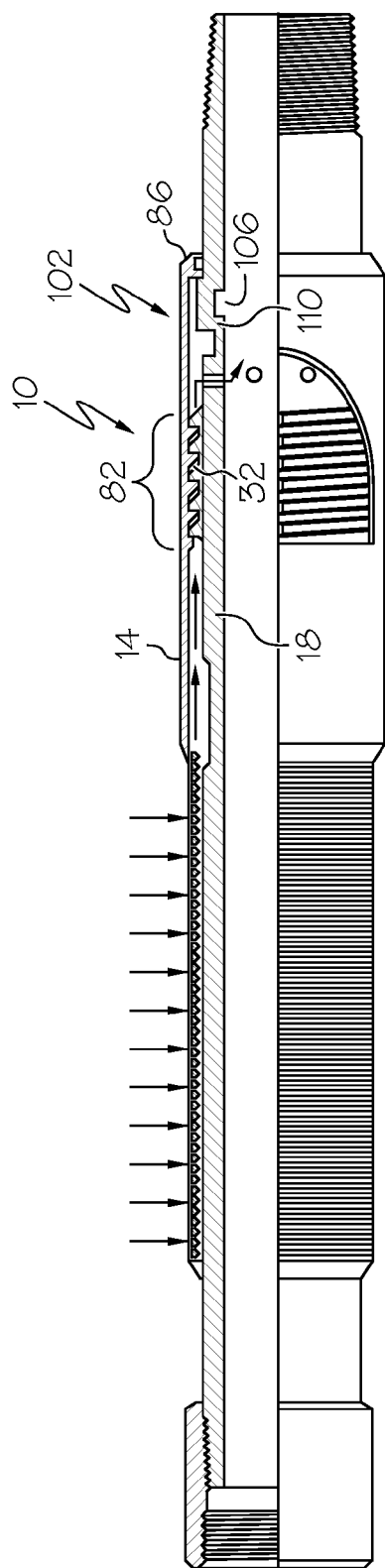


FIG. 4A

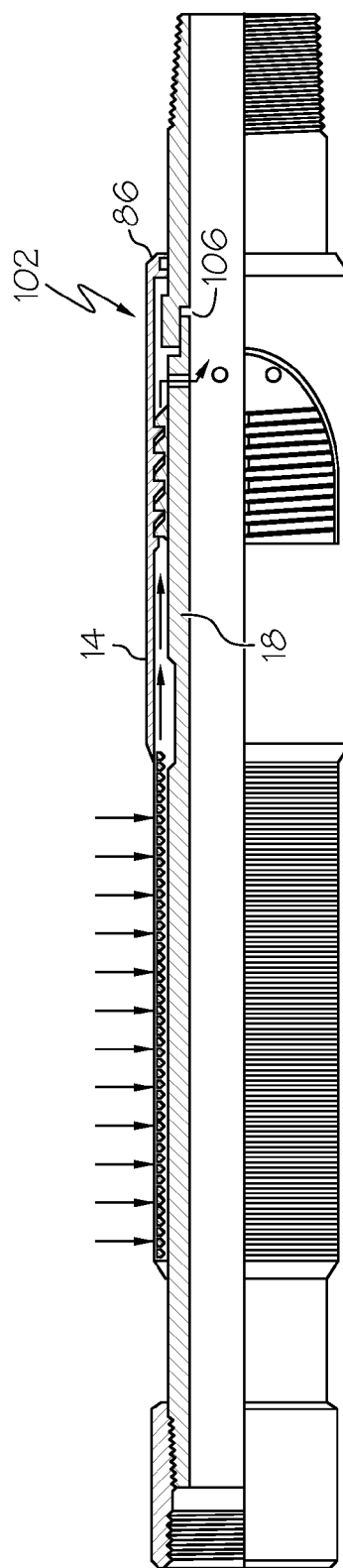


FIG. 4B



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## DOWNHOLE FLOW CONTROL DEVICE AND METHOD

### CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Divisional of U.S. Non Provisional application Ser. No. 12/136,377, filed on Jun. 10, 2008, and claims priority to U.S. Provisional Application No. 61/052,919, filed on May 13, 2008, which patent applications are incorporated herein by reference in their entireties.

### BACKGROUND

The following disclosure relates to a method and system for equalizing recovery of hydrocarbons from wells with multiple production zones having varying flow characteristics.

In long wells with multiple producing zones, the temperatures can vary between the zones thereby having an effect on the production rate and ultimately the total production from the various zones. For example, a high flowing zone can increase in temperature due to the friction of fluid flowing therethrough with high velocity. Such an increase in fluid temperature can decrease the viscosity of the fluid, thereby tending to further increase the flow rate. These conditions can result in depletion of hydrocarbons from the high flowing zones, while recovering relatively little hydrocarbon fluid from the low flowing zones. Systems and methods to equalize the hydrocarbon recovery rate from multi-zone wells would therefore be well received in the art.

### BRIEF DESCRIPTION OF THE INVENTION

A flow control device, including a first member defining a first portion of a flow path; a second member defining a second portion of the flow path, the flow path having a cross sectional flow area defined at least partially by the first member and the second member, a length of the flow path being greater than a largest dimension of the cross sectional flow area, and the cross sectional flow area being adjustable by movement of at least a portion of the first member relative to the second member; and a crush zone arranged with at least one of the first member and the second member that can change in length due to loading thereof.

A method of adjusting restriction of a downhole flow path, including porting fluid through the downhole flow path, the downhole flow path having a length greater than a largest dimension of a cross sectional area of the downhole flow path; moving at least a portion of one of a first member defining a first portion of the downhole flow path and a second member defining a second portion of the downhole flow path relative to the other of the first member and the second member such that the cross sectional area is altered; and loading a crush zone arranged with at least one of the first member and the second member for changing an alterable length of the crush zone.

### BRIEF DESCRIPTION OF THE DRAWINGS

The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. 1 depicts a partial cross sectional side view of a downhole flow control device disclosed herein;

FIG. 2 depicts a cross sectional side view of the flow control device at less magnification;

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FIG. 3 depicts the flow control device of FIG. 1 with an alternate actuation mechanism;

FIG. 4A depicts the flow control device of FIG. 1 with yet another actuation mechanism with the actuation mechanism in the non-actuated state; and

FIG. 4B depicts the flow control device of FIG. 1 with the actuation mechanism of FIG. 4A in the actuated state.

### DETAILED DESCRIPTION OF THE INVENTION

A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

Referring to FIG. 1, an embodiment of a downhole flow control device 10, disclosed herein, is illustrated. The control device 10 includes, a first tubular member 14 and a second tubular member 18 defining a first annular flow space 22 and a second annular flow space 26 therebetween. A helical flow path 30 fluidically connects the first annular flow space 22 with the second annular flow space 26. The helical flow path 30, has a cross sectional flow area 32, defined by clearance between helical radially inwardly protruding threads 34, of the first tubular member 14, and helical radially outwardly protruding threads 38, of the second tubular member 18. The cross sectional flow area 32 of the helical flow path 30 is adjustable such that the flow rate therethrough can be throttled. The adjustment can be performed automatically based upon downhole conditions such as flow rate and temperature, for example. Employing multiple helical flow paths 30 in a single tubular string can automatically reduce production in high flowing zones, while not reducing production in low flowing zones automatically to equalize the zones and potentially extract more total hydrocarbon from the well.

In the embodiment of FIG. 1, the first annular flow space 22 is fluidically connected to an annular space 42 between the first tubular member 14 and an inner perimetrical surface 46 of a formation, liner or other tubular structure, for example. The second annular flow space 26 is fluidically connected to an inner flow space 50 defined by an inner radial portion of the second tubular member 18. As such, fluid is permitted to flow through a screen 54, through the first annular flow space 22, in the direction of arrows 58, through the flow path 30, through the second annular flow space 26, in the direction of arrows 62 and through a port 66 into the inner flow space 50. It should be noted that in alternate embodiments the fluid that flows through the helical flow path 30 could originate from and end up in alternate locations or directions than those illustrated herein.

The helical flow path 30 can be designed to circumnavigate the second tubular member 18 as many times as desired with the flow path 30 illustrated herein, completing approximately four complete revolutions. A length of the flow path 30 is, therefore, much greater than a largest dimension of the cross sectional flow area 32. As such, viscous drag along surfaces that define the cross sectional flow area 32 create a pressure drop as fluid flows therethrough. This pressure drop can be substantial, particularly in comparison to the pressure drop that would result from the cross sectional flow area 32 if the length of the flow path 30 were less than the largest dimension of the cross sectional flow area 32. Embodiments disclosed herein allow for adjustment of the cross sectional flow area 32 including automatic adjustment of the cross sectional flow area 32 as will be discussed in detail with reference to the figures.

Additionally, the first tubular member 14 is axially movable relative to the second tubular member 18. As the first

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tubular member 14 is moved leftward as viewed in FIG. 1, the cross sectional flow area 32 will decrease since the threads 34 will move closer to the threads 38. One or more seals (not shown) seal the opposing ends of threads 34 to threads 38 to prevent fluid flow from flowing through any clearance developed on the back sides of the threads 34, 38 when the first tubular 14 is moved.

Referring to FIG. 2, the flow control device 10 is shown in an embodiment wherein the movement of the first tubular member 14 is actuated by dimensional changes in the first tubular member 14. The first tubular member 14 is fabricated from a first portion 78 and a second portion 82. The threads 34 are located in the second portion 82. The first portion 78 is fixedly attached to the second tubular 18 at attachment 86 by, for example, threaded engagement, welding or similar method. The attachment 86 prevents relative motion between the two tubulars 14, 18 at the point of the attachment 86. However, relative motion between the second portion 82 and the second tubular member 18 is desirable and controllable. The first tubular member 14, including both the portions 78 and 82, are fabricated from a material having a first coefficient of thermal expansion while the second tubular member 18 is fabricated from a different material having a second coefficient of thermal expansion. The foregoing construction will result in the first tubular member 14 expanding axially at a rate, with changes in temperature, that is different than the axial expansion of the second tubular member 18. Since the fluid flow is in the annular flow spaces 22, 26 between the two tubulars 14, 18, the tubulars 14, 18 will maintain approximately the same temperature. By setting the coefficient of thermal expansion for the first tubular member 14 greater than that of the second tubular member 18, the cross sectional flow area 32 will decrease as the temperature of the flow control device 10 increases. This can be used to automatically restrict a high flowing zone in response to increases in temperature of the device 10 due to friction of the fluid flowing therethrough. Conversely, in low flowing zones, the decreased friction will maintain the device 10 at lower temperatures, thereby maintaining the cross sectional flow area 32 at larger values near the original value.

Additionally, the flow control device 10 can be used to equalize the flow of steam in a steam injection well. Portions of a well having higher flow rates of steam will have greater increases in temperature that will result in greater expansion of the first tubular member 14, thereby restricting flow of steam therethrough. Conversely, portions of the well having less flow of steam will have less increases in temperature, which will result in little or no expansion of the first tubular 14, thereby maintaining the cross sectional flow area 32 at or near its original value. This original cross sectional flow area 32 allows for the least restrictive flow of steam to promote higher flow rates. The flow control device 10 can, therefore, be used to equalize the injection of steam in a steam injection well and to equalize the recovery of hydrocarbons in a producing well.

In the foregoing embodiment, the second portion 82 was made of a material with a different coefficient of thermal expansion than the second tubular member 18. In addition to contributing to the movement of the second portion 82, this also causes a change in pitch of the thread 34 that is different than a change in pitch of the thread 38. Consequently, the cross sectional flow area 32 varies over the length of the flow path 30. Since, in the above example, the second portion 82 expands more than the second tubular member 18, the pitch of the thread 34 will increase more than the pitch of the thread

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38. The cross sectional flow area 32 will, therefore, decrease more at points further from the attachment 86 than at points nearer to the attachment 86.

Keeping the cross sectional flow area 32 constant over the length of the flow path 30 can be accomplished by fabricating the second portion 82 from the same material, or a material having the same coefficient of thermal expansion, as the second tubular member 18. If the second portion 82 and the second tubular member 18 have the same coefficient of thermal expansion, then the pitch of the threads 34 will change at the same rate, with changes in temperature, as the pitch of the threads 38. Note that this constancy of the flow area 32 is over the length of the flow path 30 only, as the overall flow area 32 as a whole over the complete flow path 30 can vary over time as the temperature of the device 10 changes. Such change results when the second portion 82 moves, or translates, relative to the second tubular member 18. Movement of the second portion 82 can be achieved in several ways, with a few being disclosed in embodiments that follow.

Referring to FIG. 3, movement of the second portion 82, in this embodiment, results from expansion of the drill string in areas outside the device 10, as well as within the device 10. As portions of the drill string heat up they expand. This expansion applies an axially compressive load throughout the drill string, which includes the second tubular member 18. A crush zone 90, located in a portion of the second tubular member 18, is designed to crush and thereby shorten axially in response to the load. The crush zone 90, illustrated in this embodiment, includes a series of convolutes 94 within a perimetrical wall 98. The convolutes 94 place portions of the wall in bending that will plastically deform at loads less than is required to cause plastic deformation of walls without convolutes. Alternate constructions of crush zones can be applied as well, such as those created by the areas of weakness as disclosed in U.S. Pat. No. 6,896,049 to Moyes, for example, the contents of which are incorporated by reference herein in their entirety. The crush zone 90 is located between the attachment 86 and the second portion 82. As the crush zone 90 shortens, the threads 38 move toward the right, as viewed in FIG. 3, and in the process causing the cross sectional flow area 32 to decrease. The decrease in the flow area 32 results in an increase in the pressure drop of fluid flowing through the flow path 30 restricting flow in the process.

Referring to FIGS. 4A and 4B, an alternate embodiment of a crush zone 102 is employed. The crush zone 102 includes a release joint 106, such as, a shear joint, for example, having a shear plane 110 in the second tubular 18. The shear plane 110 shears at a selected level of compressive load. Upon shearing, the shear joint 106 is axially shortened. By placing the shear joint 106, between the attachment 86 and the second portion 82, the cross sectional flow area 32 is made to decrease upon axial shortening of the shear joint 106, as depicted in FIG. 4B.

While the invention has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the claims. Also, in the drawings and the description, there have been disclosed exemplary embodiments of the invention and, although specific terms may have been employed, they are unless other-

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wise stated used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention therefore not being so limited. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

What is claimed is:

1. A flow control device, comprising:

a first member defining a first portion of a cross section of a flow path;

a second member defining a second portion of the cross section of the flow path, the second member being distinct from and operably coupled with the first member, the flow path having a cross sectional flow area defined at least partially by the first portion and the second portion, a length of the flow path being greater than a largest dimension of the cross sectional flow area, and the cross sectional flow area being adjustable by axial movement of at least a portion of the first member relative to the second member; and

a crush zone arranged with at least one of the first member and the second member that can change in length due to loading thereof, at least a portion of the crush zone being configured to undergo plastic deformation due to the loading thereof and resulting in the movement of at least a portion of the first member relative to the second member.

2. The flow control device of claim 1, wherein the cross sectional flow area is altered at every point along the flow path in response to the movement.

3. The flow control device of claim 1, wherein the first member is tubular with a radially inwardly protruding thread and the second member is tubular with a radially outwardly protruding thread and the radially outwardly protruding thread extends radially outwardly a dimension greater than a minimum dimension of the radially inwardly protruding thread.

4. The flow control device of claim 3, wherein clearance between the radially inwardly protruding thread and the radially outwardly protruding thread defines the flow path.

5. The flow control device of claim 1, wherein a plurality of the flow control devices are incorporated in a well to equalize at least one of injection of steam and production of hydrocarbons along the well.

6. The flow control device of claim 1, wherein the at least one crush zone changes in axial length in response to axial loading thereof.

7. The flow control device of claim 1, wherein the at least one crush zone includes at least one shear joint.

8. The flow control device of claim 1, wherein the crush zone includes at least one convolute.

9. The flow control device of claim 1, wherein the device is arranged downhole.

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10. A flow control device, comprising:

a first member defining a first portion of a cross section of a flow path;

a second member defining a second portion of the cross section of the flow path, the second member being distinct from and operably coupled with the first member, the flow path having a cross sectional flow area defined at least partially by the first portion and the second portion, a length of the flow path being greater than a largest dimension of the cross sectional flow area and the cross sectional flow area being adjustable by movement of at least a portion of the first member relative to the second member; and

a crush zone arranged with at least one of the first member and the second member that can change in length due to loading thereof, at least a portion of the crush zone being configured to undergo plastic deformation due to the loading thereof and resulting in the movement of at least a portion of the first member relative to the second member,

wherein the flow path has a helical shape.

11. A method of adjusting restriction of a flow path, comprising:

porting fluid through the flow path, the flow path having a length greater than a largest dimension of a cross sectional area of the flow path; and

altering the cross sectional area of the flow path by loading a crush zone to plastically deform at least a portion of the crush zone thereby changing an alterable length of the crush zone, the crush zone arranged with at least one of a first member defining a first portion of a cross section of the flow path and a second member, distinct from and operably coupled with the first member, defining a second portion of the cross section of the flow path, the loading of the crush zone resulting in axial movement of the first member relative to the second member such that the cross sectional area is altered.

12. The method of adjusting restriction of a flow path of claim 11, further comprising shortening the crush zone arranged with the at least one of the first member and the second member.

13. The method of adjusting restriction of a flow path of claim 12, wherein shortening the crush zone includes compressing at least one convolution of the crush zone.

14. The method of adjusting restriction of a flow path of claim 12, wherein shortening the crush zone includes shearing at least one shear joint of the crush zone.

15. The method of adjusting restriction of a flow path of claim 11, wherein loading the crush zone includes axially loading the crush zone.

16. The method of adjusting restriction of a flow path of claim 11, further comprising arranging a tubular string containing the first member and the second member downhole.

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